

Experimental Analysis of Mast Lifting and Bending Forces on Vibration Patterns Before and After Pinion Reinstallation in an OH-58 Transmission Test Rig

Edward M. Huff and Eric Barszcz
NASA Ames Research Center

Irem Y. Tumer
Caelum Research Corporation
NASA Ames Research Center

David Lewicki and Harry Decker
U.S. Army Research Laboratories

Summary:

As part of a cooperative research program between NASA Ames Research Center, NASA Glenn Research Center, and the U.S. Army Laboratories, a series of experiments are being performed on the 500 HP OH-58a Transmission Test Rig at NASA Glenn Research Center. The findings reported in this paper were drawn from Phase 1 of a two-phase experiment, and are focused on the vibration response of an undamaged pinion gear and planetary system operating *in situ* in the transmission test rig. Phase 2 of the experiment, which is reported elsewhere, introduced a seeded fault into the pinion gear and tracked its progress in real-time. Based on methods presented here, further experimental research will be conducted to examine planetary system faults.

Objectives:

The first phase of the experiment was designed with three goals in mind:

1. Determine vibration patterns due to combinations of three operating parameters, i.e., torque, mast lifting, and mast bending, so as to simulate in-flight forces on the transmission.
2. Evaluate pattern changes attributable to disassembly and reinstallation of the main pinion gear assembly.
3. Provide reference time-series data for use as a comparative baseline for Phase 2, which involved disassembly and reinstallation of the pinion gear with a seeded tooth fault.

Method:

The experimental design is based on a $3 \times 2 \times 2 \times 2$ fixed-effects analysis of variance (ANOVA). Three levels of torque (40, 80, 100%) correspond with the first factor; two levels of mast lift (45, 100%) correspond with the second factor; two levels of mast bending (off, on) correspond with the third factor; and two

pinion installations (1, 2) correspond with the fourth factor. During Phase 1a, all twelve combinations of the first three variables were run in the order shown in Table 1. In each case, 12 "replications" were recorded in succession. Following disassembly and reinstallation of the pinion gear, the same treatment conditions were repeated, and similar data were collected during Phase 1b.

Once transient effects diminished at each operational test point, data were collected continuously for twelve successive 33 sec. periods at 120kHz, from five single-axis accelerometers, two tachometers, and a proximity probe. Two accelerometers were placed radially and axially, respectively, on a mounting block at the input pinion shaft housing, and two accelerometers were placed in pre-drilled mounting sites at 45- and 225-degree positions on the planetary gear housing. A fifth accelerometer was positioned near the 45-degree accelerometer on a bracket that was later to be used on the Ames OH-58c aircraft. (This allowed for evaluating the resonance frequency and transfer function of the aircraft mounting bracket.) The two tachometer signals monitored the input and output shafts, respectively, to allow synchronous time averaging of the various accelerometer signals.

Table 1: Experimental Treatment Combinations.

| Operating Point | Torque (% of Max) | Mast Lift (% of Max. GW) | Mast Bending (0-off, 1-on) |
|-----------------|-------------------|--------------------------|----------------------------|
| 1 | 40 % | 45 % | 0 |
| 2 | 40 % | 45 % | 1 |
| 3 | 40 % | 100 % | 0 |
| 4 | 40 % | 100 % | 1 |
| 5 | 80 % | 45 % | 0 |
| 6 | 80 % | 45 % | 1 |
| 7 | 80 % | 100 % | 0 |
| 8 | 80 % | 100 % | 1 |
| 9 | 100 % | 45 % | 0 |
| 10 | 100 % | 45 % | 1 |
| 11 | 100 % | 100 % | 0 |
| 12 | 100 % | 100 % | 1 |

Results:

In making ready for Phase 2 of the experiment, a comparative evaluation was made of the twelve treatment conditions before and after disassembly and re-assembly of the pinion gear. This was done by applying the Kolmogorov-Smirnov non-parametric test to the cumulative power spectral distributions obtained from the radial pinion accelerometer. A uniform effect was observed at 40% torque in that each treatment condition had a significantly different spectral content after the pinion was reinstalled. Since a concerted effort was made to realign the teeth exactly during reinstallation, an obvious physical explanation was not clear. Significant differences were not found at the 80% and 100% torque

levels, although the K-S test statistic was stochastically larger at 80% than 100%, clearly suggesting that the frequency distribution effect is uniform and inversely related to torque.

A composite picture of all possible power spectral comparisons for Phase 1b is shown graphically in Fig. 1. A black "dot" indicates a statistical difference, and a white dot indicates no difference in the test comparison. Preliminary conclusions based on this technique are that torque has the most significant effect on the spectral distribution; mast lift has a secondary effect, and mast bending has the least effect. Again, lifting- and bending-force effects are inversely related to torque level.

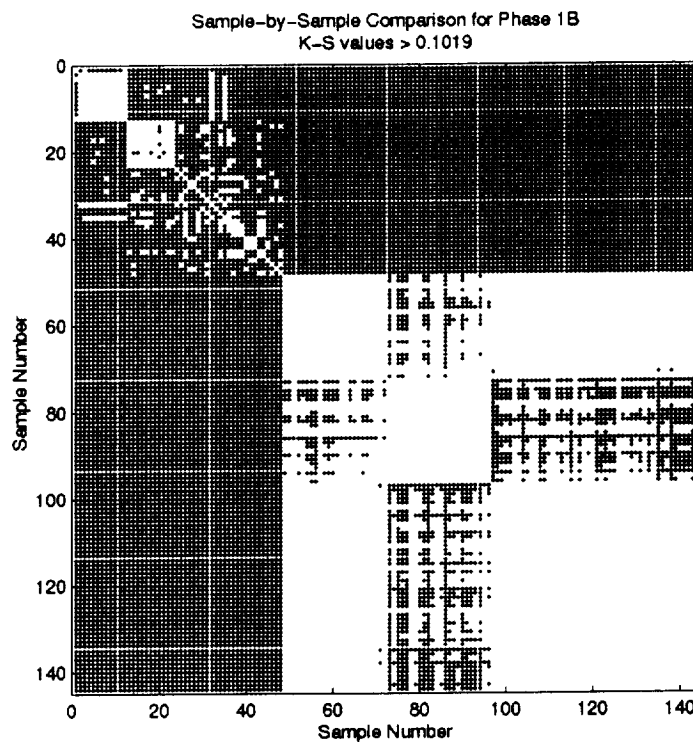


Figure 1. Composite K-S test results for Phase 1b.

Figure 2 shows a combined plot of the total spectral power of all treatment replications for Phase 1a and Phase 1b. It is clear that there were uniform and highly significant differences before and after pinion re-assembly, which are directly related in magnitude to the torque level. This was confirmed statistically by a four-way ANOVA, which found a significant reinstallation effect. Combined with the previous power-spectral comparisons, the weight of evidence clearly supports the conclusion that reliable changes are induced in the pinion vibration pattern due to the installation process alone. With regard to spectral power, this effect was stronger than lifting or bending forces applied to the transmission at higher torque values. By contrast, spectral content changes were observable primarily at the lower torque levels.

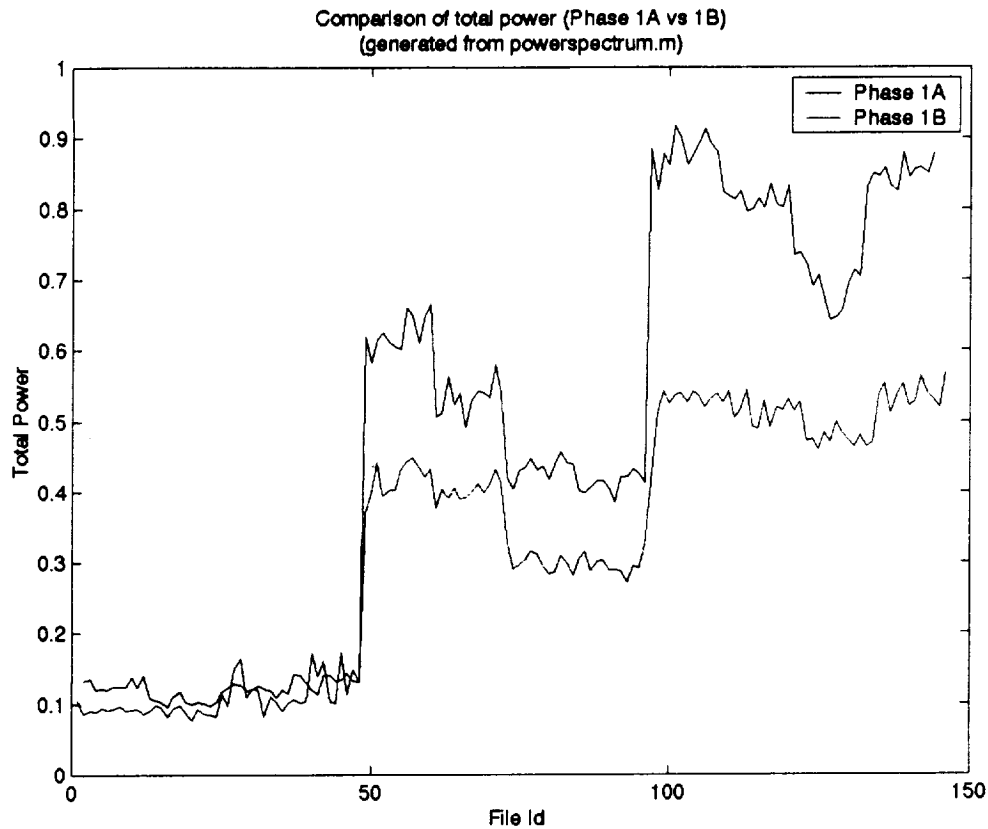


Figure 2. Comparison of Total Power to Determine Reinstallation Effects.

Conclusions:

Results from this experiment indicate that there are significant variations introduced in pinion vibration patterns due to changes in three primary operational parameters. In particular, torque has the most dominant effect on the pinion gear vibration, followed in order of importance by mast lifting forces, and mast bending forces. In addition, the results indicate that there may be significant differences introduced in pinion vibration patterns simply by reinstallation of the main pinion gear itself. If this conclusion is supported in future research, it has strong implications for the impact of maintenance operations on in flight HUMS analysis.